Intelligent Systems Design

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Outline

Current state of the art

Near term prospects

Long term potential

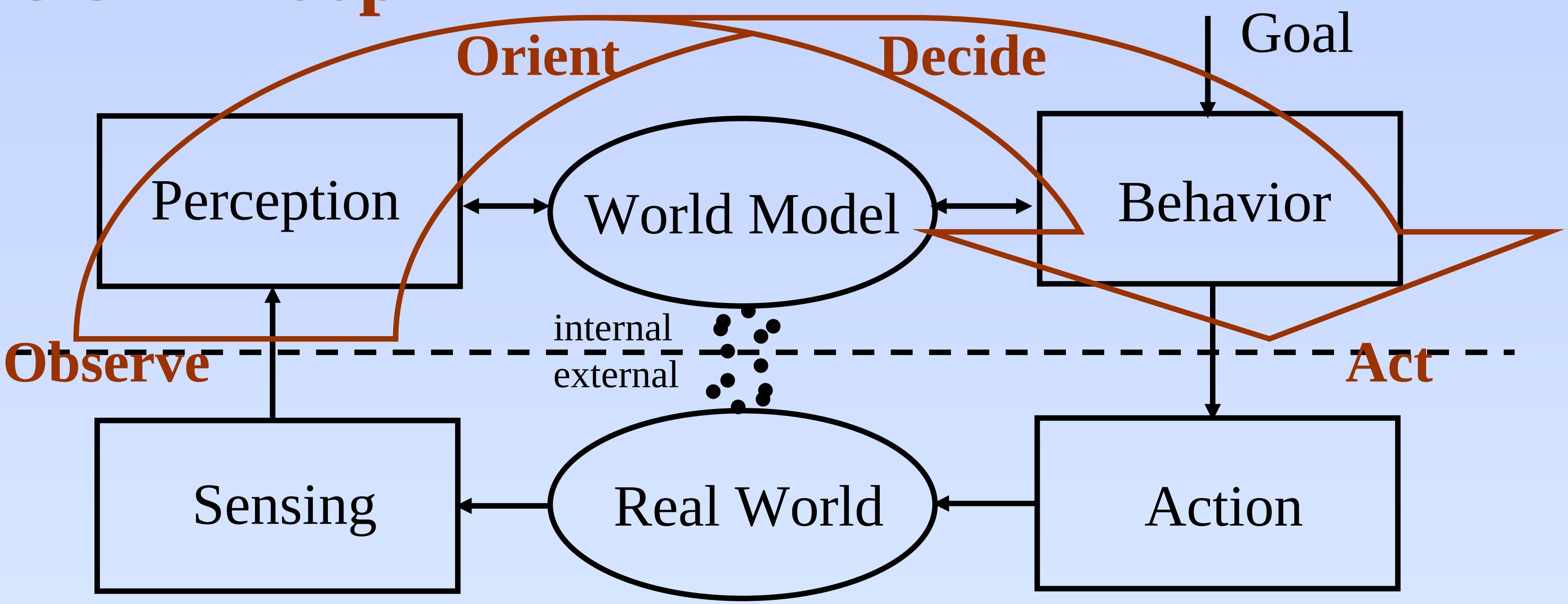
4D/RCS Reference Model Architecture for Unmanned Vehicle Systems

Developed by NIST for ARL Demo III Program
Adopted by GDRS for FCS Autonomous Navigation System
Adopted by TARDEC for Vetronics Technology Integration

- **Hierarchical structure of goals and commands**
- **Representation of the world at many levels**
- **Planning, replanning, and reacting at many levels**
- **Integration of many sensors stereo CCD & FLIR, LADAR, radar, inertial, acoustic, GPS, internal**

Basic Intelligent System

OODA loop

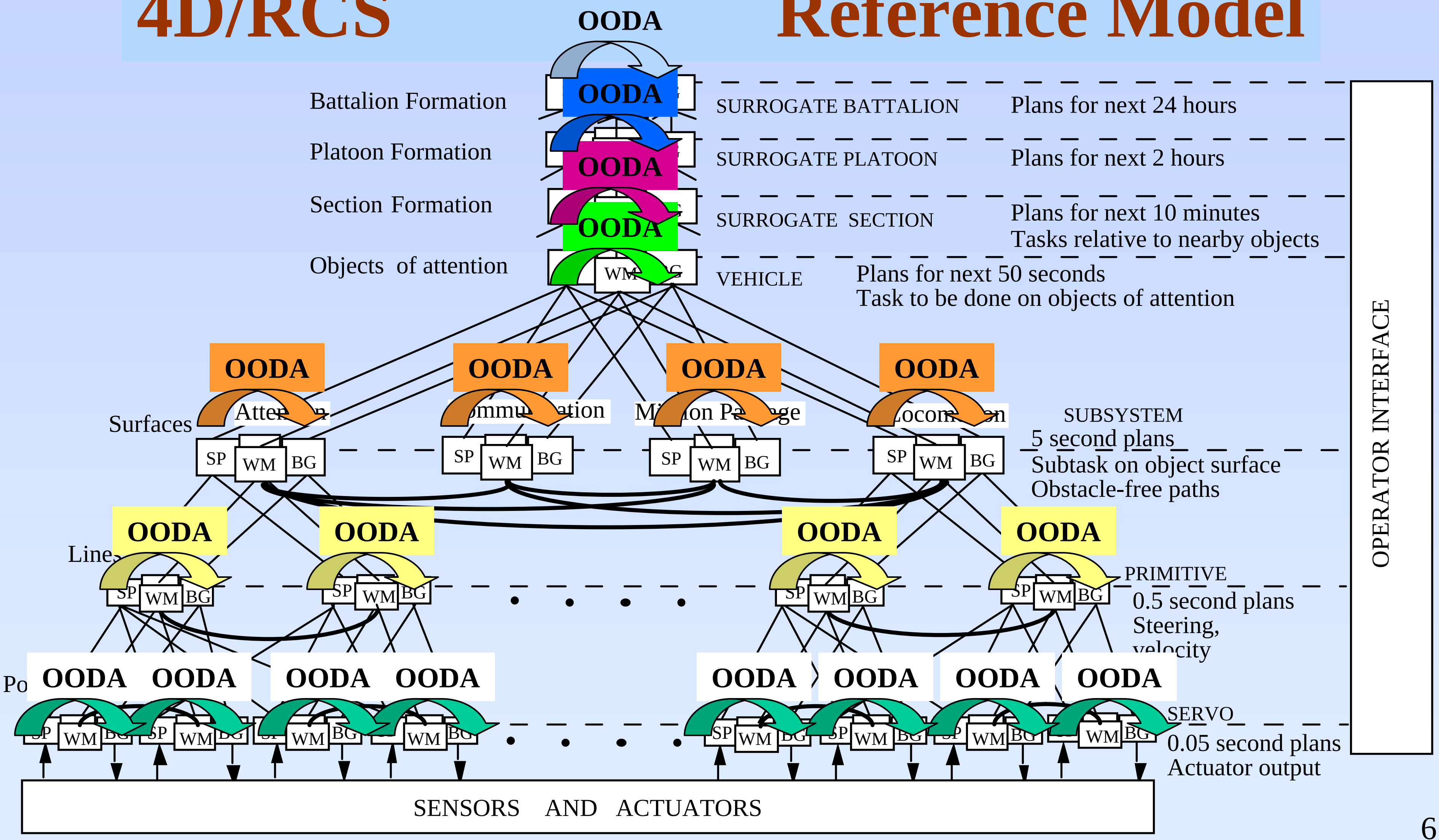


Perception establishes correspondence between internal world model and external real world

Behavior uses world model to generate action to achieve goals

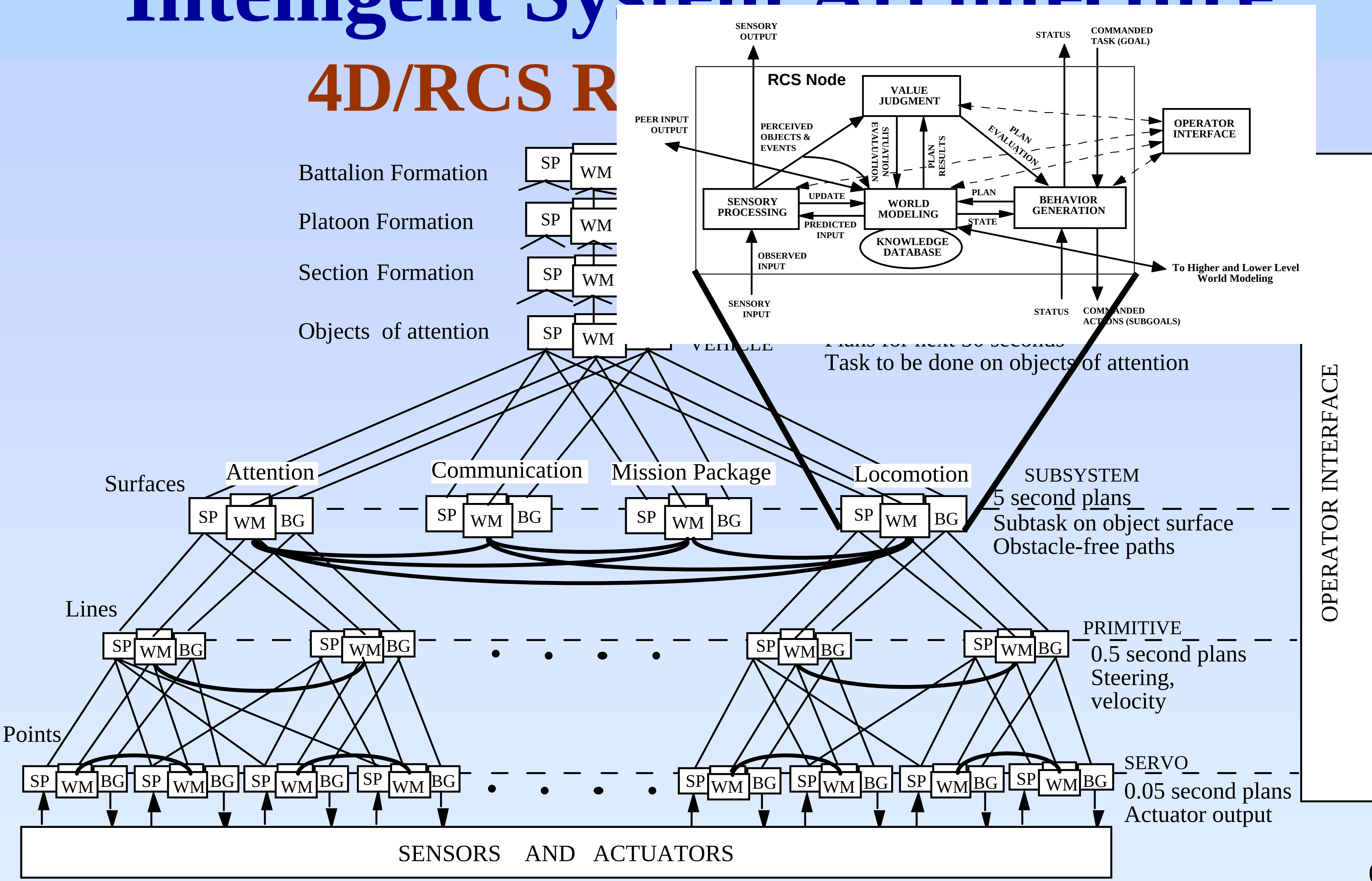
Intelligent System Architecture

4D/RCS Reference Model



Intelligent System Architecture

4D/RCS R



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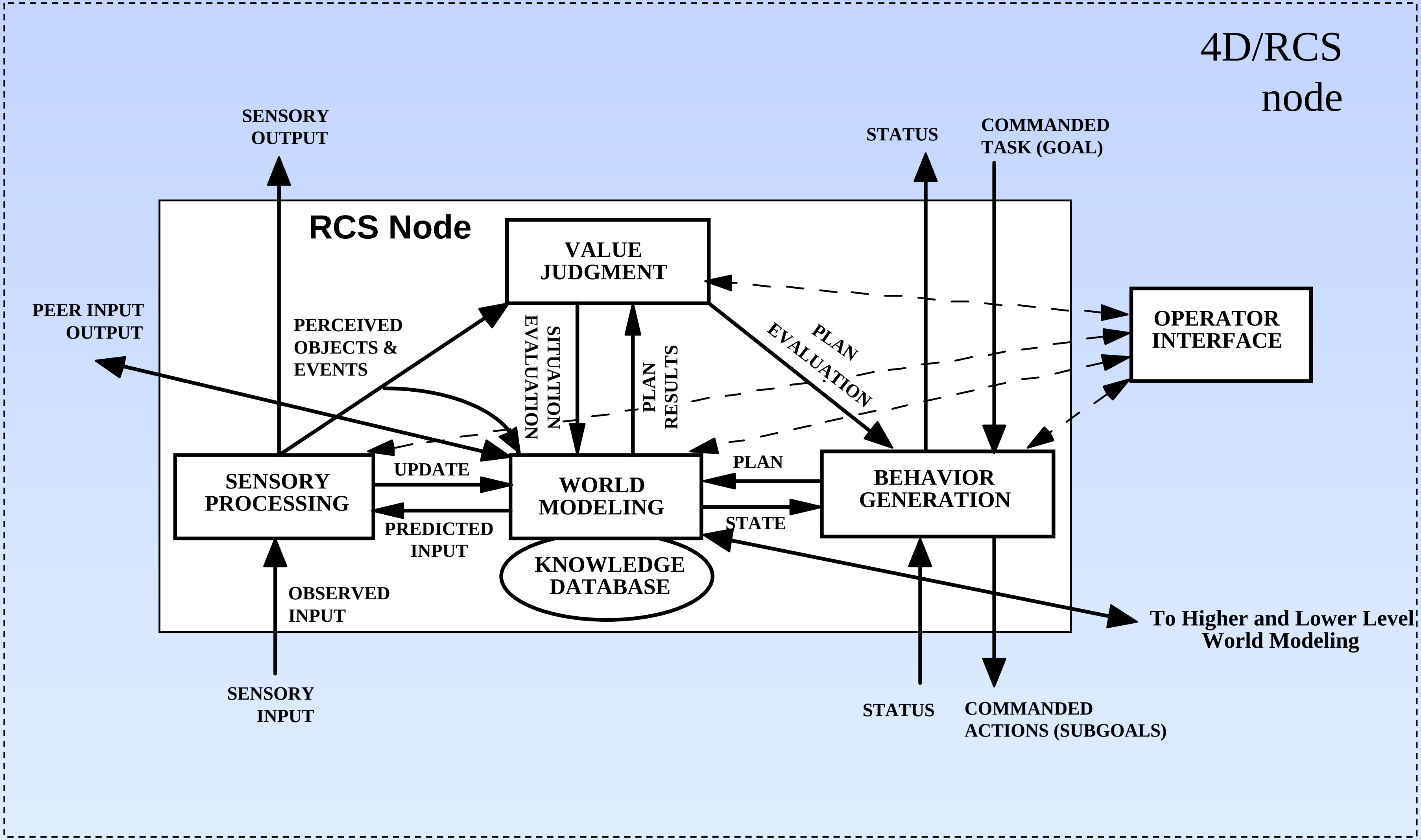
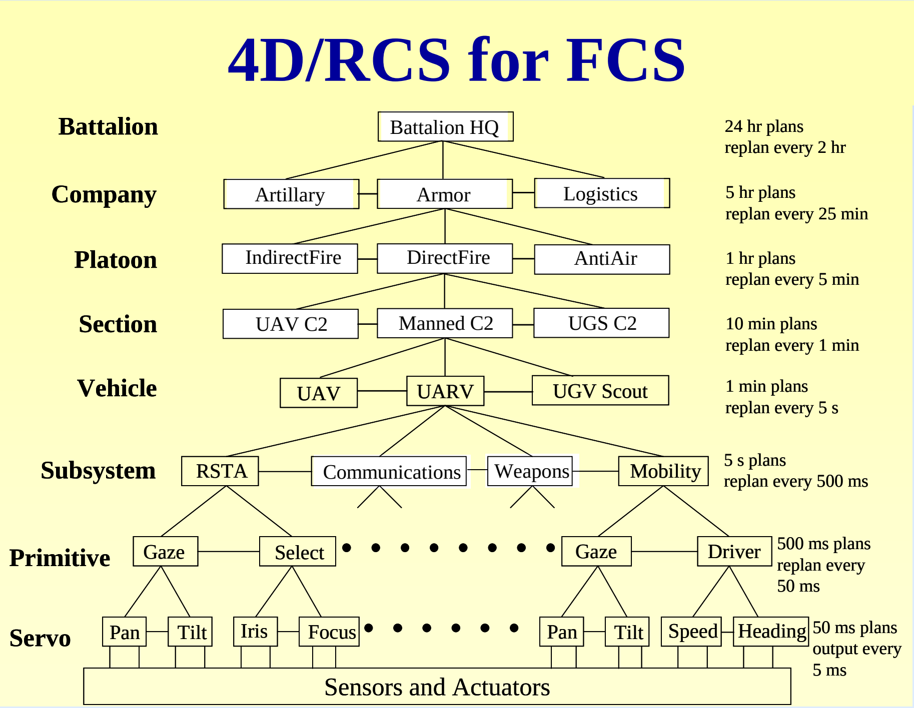
A 4D/RCS Computational Node



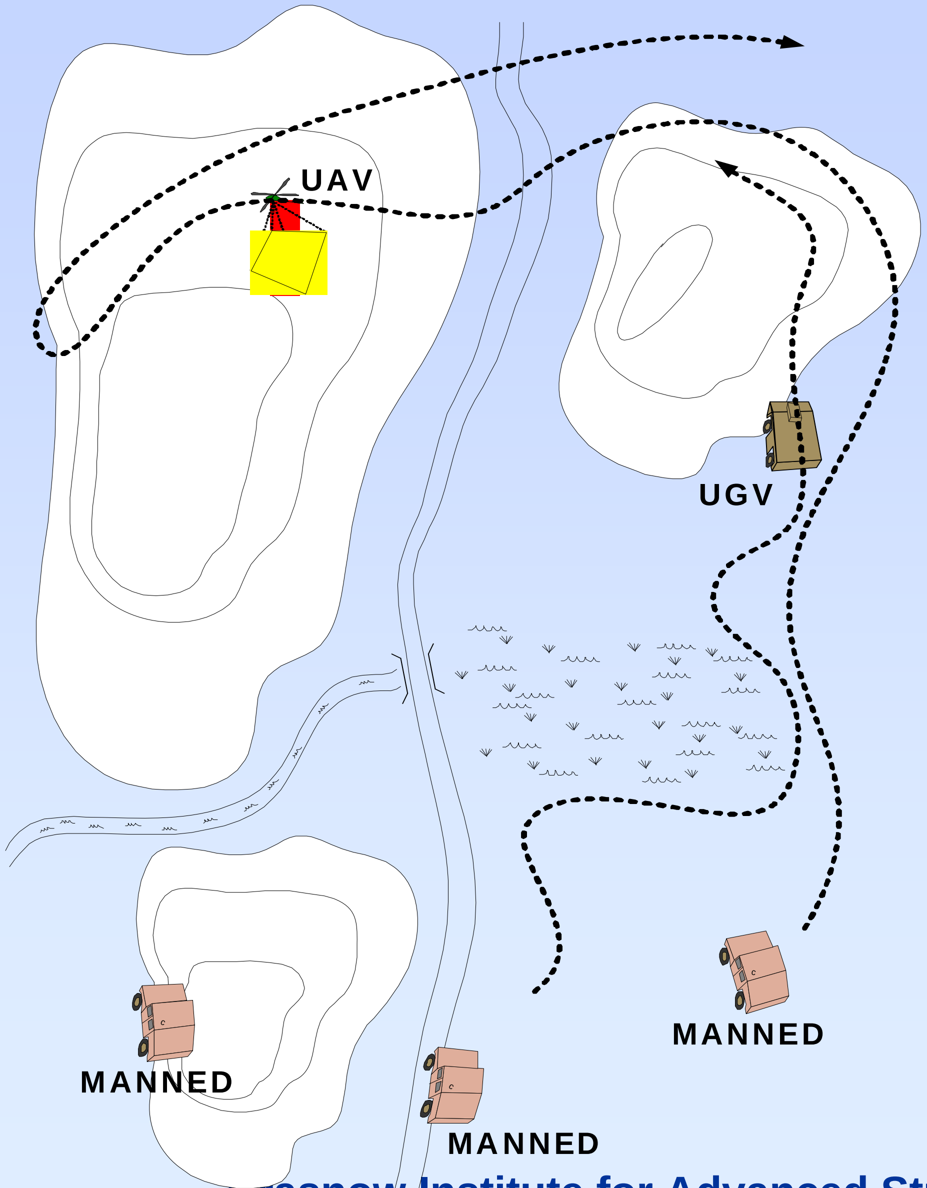
Near Term Prospects

The 4D/RCS methdology promises the ability for manned-unmanned collaboration to perform tactical behavior

Company level – 30 to 40 vehicles
Platoon level – 8 to 10 vehicles
Section level – 2 to 4 vehicles
Vehicle level – single vehicle



An Example Scenario



Scout section conducting a route reconnaissance

HMMWV reconnoitering the right flank encounters an unexpected water obstacle

Center HMMWV encounters a bridge

The two vehicle commanders report their findings to the section leader

The section leader then commands the manned vehicles to take up overwatch positions for near-side security

The section leader commands the UAV to look for a route around the water obstacle UAV sends hi-resolution color images data back to the section leader for manual viewing, and/or by scanning the ground with a LADAR to assess the topography

Once a potential by-pass to the marsh is located, the UAV is commanded to search the far side of the marsh and the region beyond the next terrain feature for evidence of enemy forces

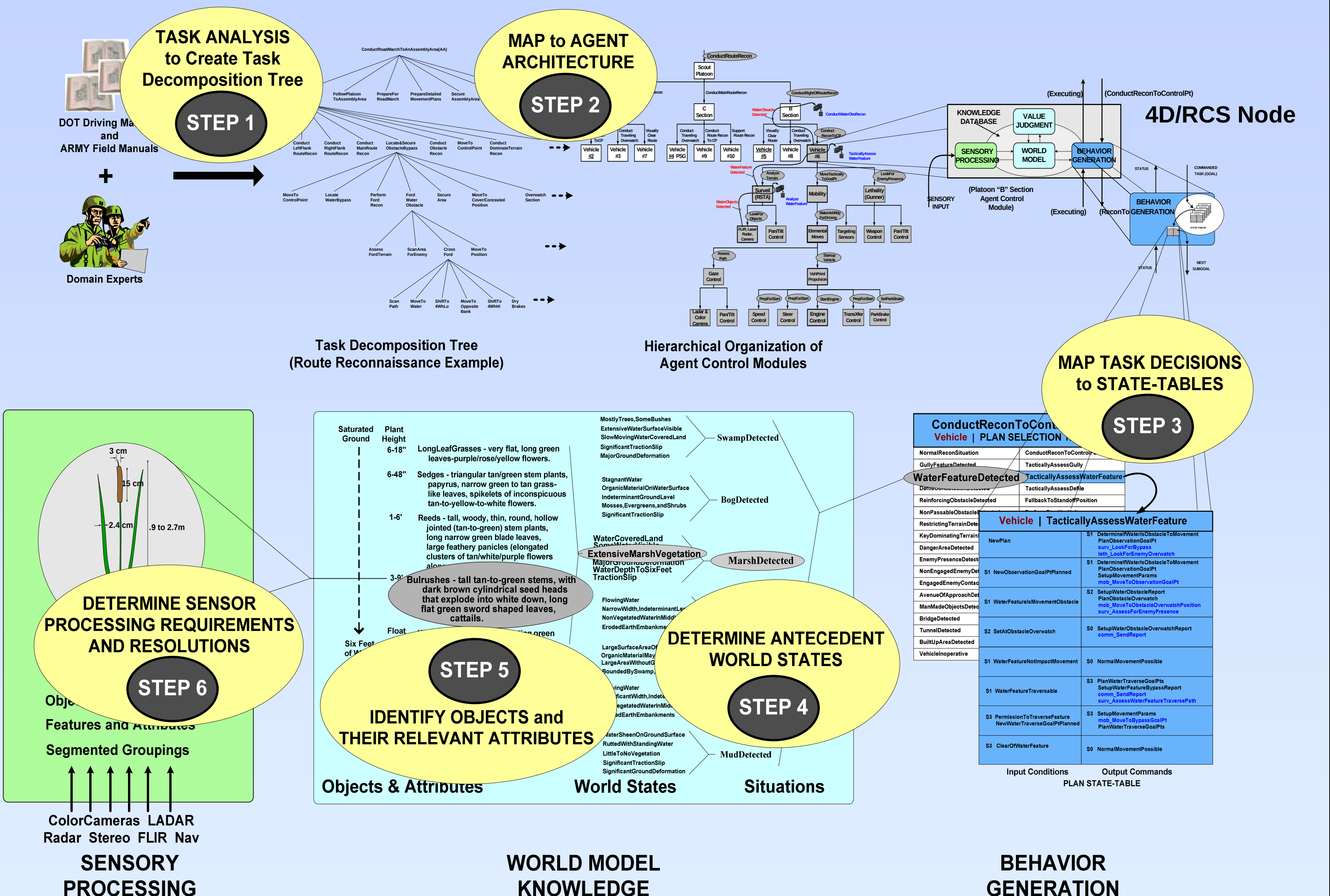
UGV is then commanded to proceed through the bypass and establish an overwatch position on the far side of the next terrain feature

The UGV path can be automatically generated from the data returned from the UAV and approved by the section leader before being executed

Once the UGV is set in position, the UAV continues scanning for enemy activity further along the route

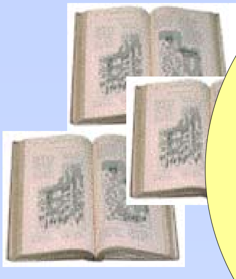
Manned elements perform manual reconnaissance of the marsh by-pass, and assess the load carrying capacity of the bridge.

Software Methodology



TASK ANALYSIS to Create Task Decomposition Tree

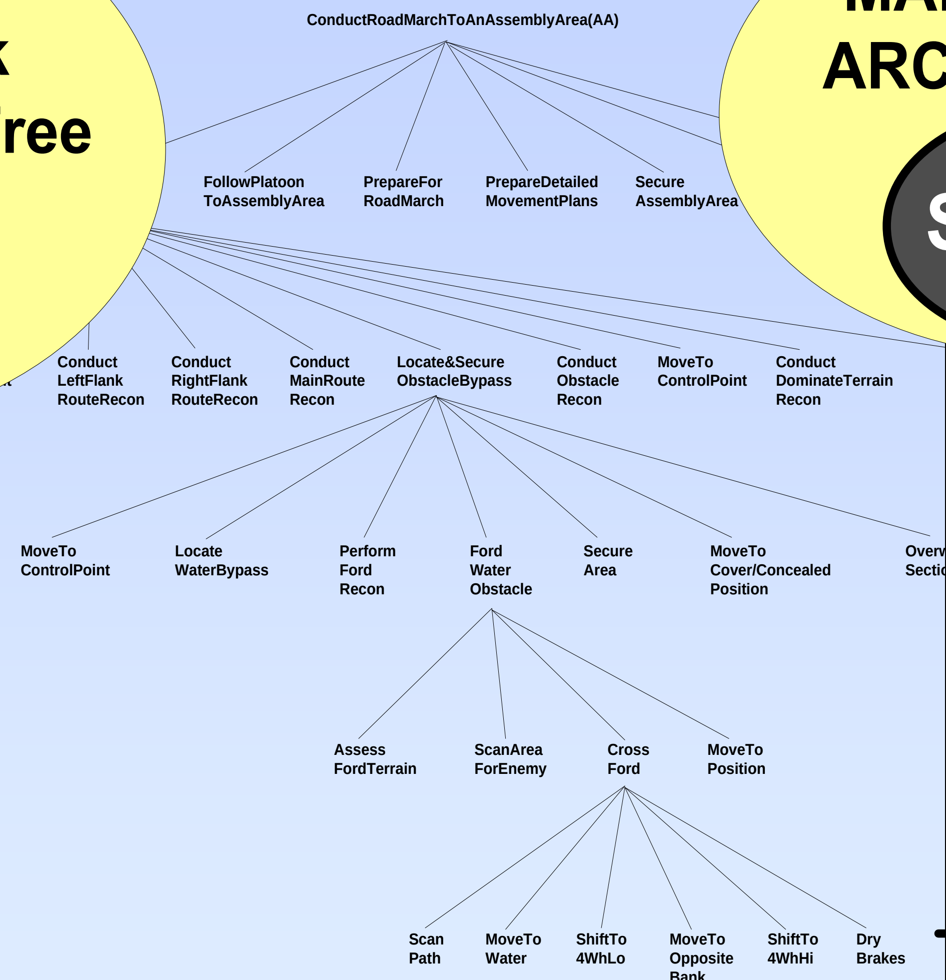
STEP 1



DOT Driving Ma
and
ARMY Field Manuals

+

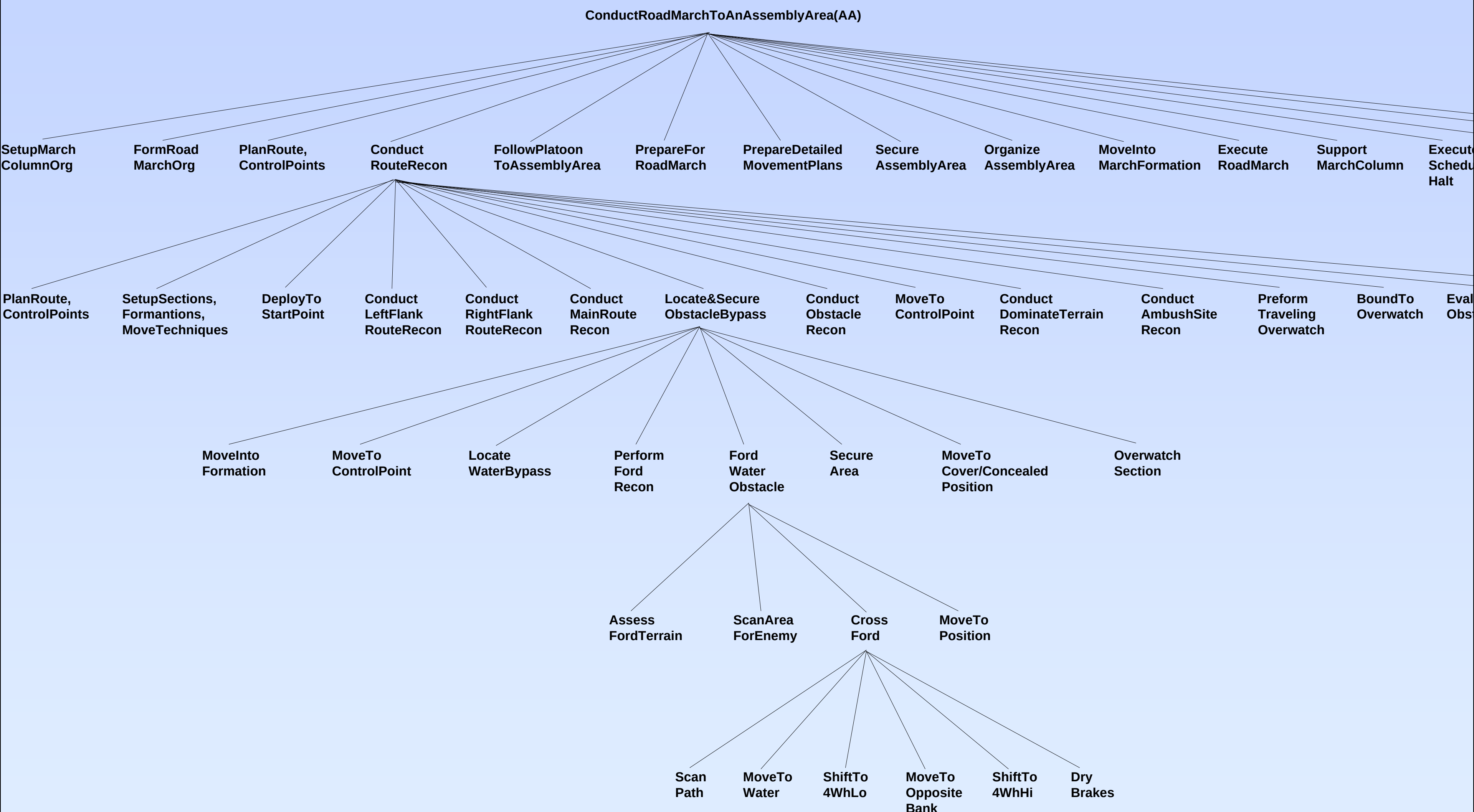
Domain Experts



Task Decomposition Tree

MA
ARC

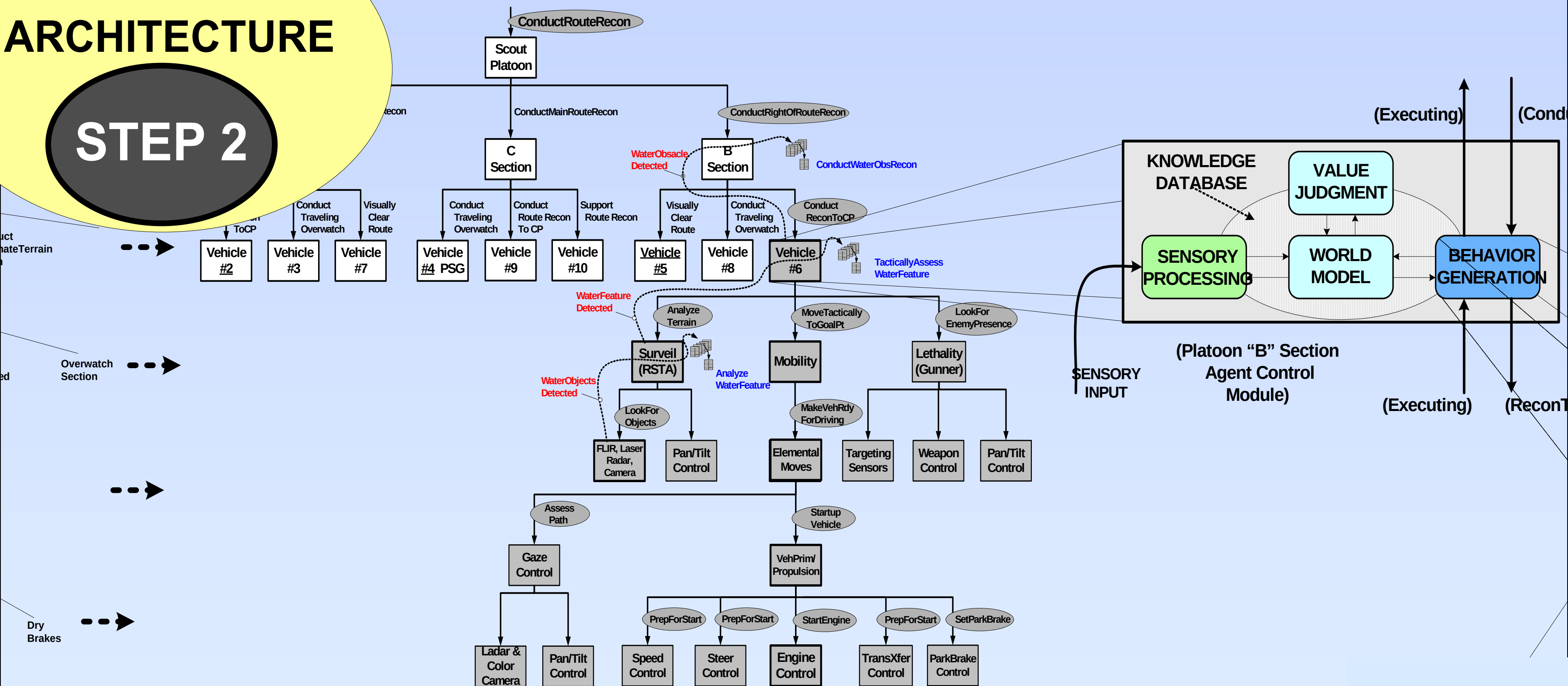
Task Vocabulary at Each Echelon



Hierarchy of Agents

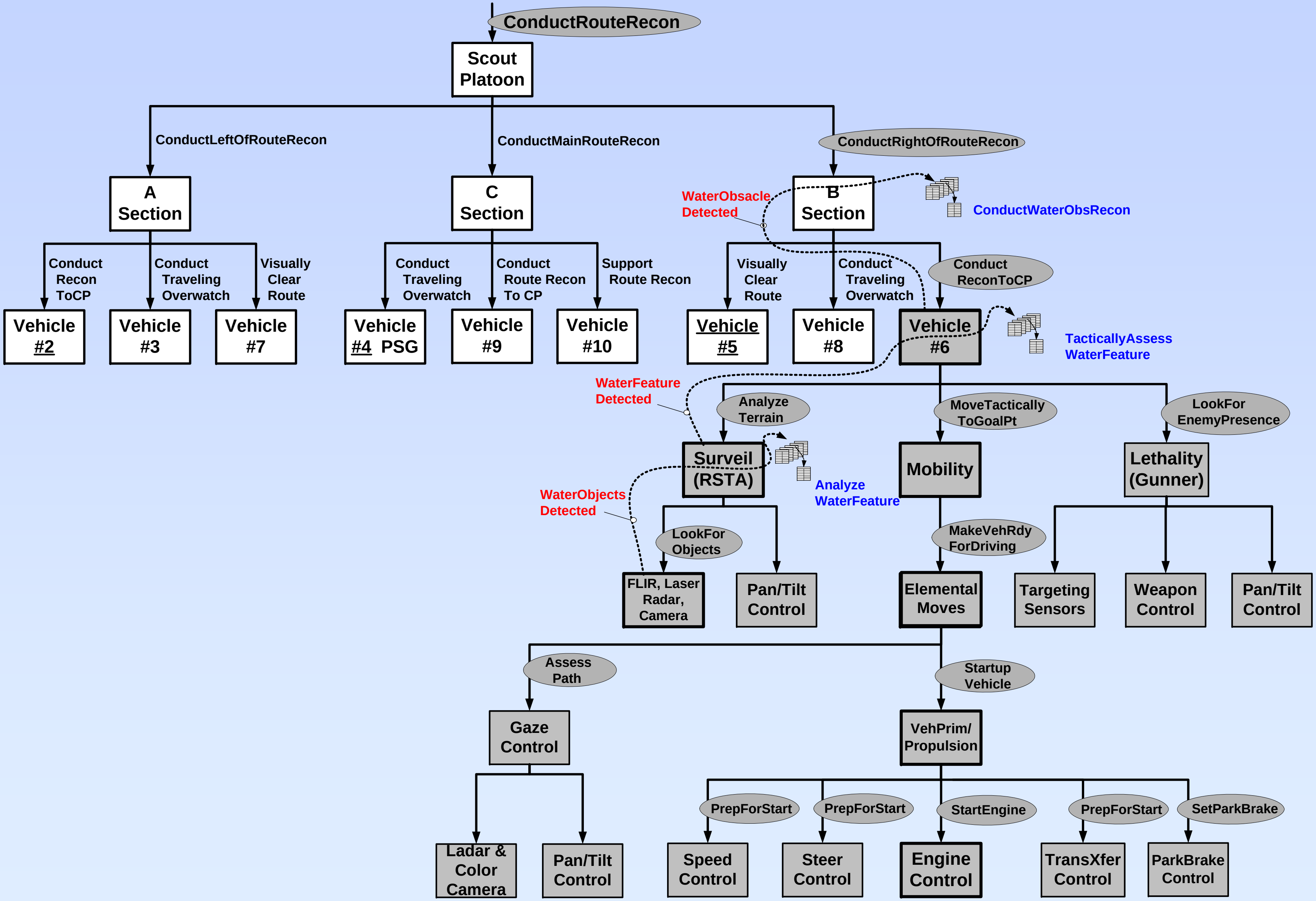
MAP to AGENT ARCHITECTURE

STEP 2



Hierarchical Organization of Agent Control Modules

Hierarchy of Agents



MAP TASK DECISIONS to STATE-TABLES

STEP 3

ConductReconToCont...
Vehicle | PLAN SELECTION ...

NormalReconSituation	ConductReconToControlP...
GullyFeatureDetected	TacticallyAssessGully
WaterFeatureDetected	TacticallyAssessWaterFeature
DefileConstrictionDetected	TacticallyAssessDefile
ReinforcingObstacleDetected	FallbackToStandoffPosition
NonPassableObstacleD...	
RestrictingTerrainDete...	
KeyDominatingTerrainI...	
DangerAreaDetected	
EnemyPresenceDetect...	
NonEngagedEnemyDet...	
EngagedEnemyContac...	
AvenueOfApproachDet...	
ManMadeObjectsDetec...	
BridgeDetected	
TunnelDetected	
BuiltUpAreaDetected	
VehicleInoperative	

Vehicle | TacticallyAssessWaterFeature

Input Conditions	Output Commands
NewPlan	S1 DetermineIfWaterIsObstacleToMovement PlanObservationGoalPt surv_LookForBypass leth_LookForEnemyOverwatch
S1 NewObservationGoalPtPlanned	S1 DetermineIfWaterIsObstacleToMovement PlanObservationGoalPt SetupMovementParams mob_MoveToObservationGoalPt
S1 WaterFeatureIsMovementObstacle	S2 SetupWaterObstacleReport PlanObstacleOverwatch mob_MoveToObstacleOverwatchPosition surv_AssessForEnemyPresence
S2 SetAtObstacleOverwatch	S0 SetupWaterObstacleOverwatchReport comm_SendReport
S1 WaterFeatureNotImpactMovement	S0 NormalMovementPossible
S1 WaterFeatureTraversable	S3 PlanWaterTraverseGoalPts SetupWaterFeatureBypassReport comm_SendReport surv_AssessWaterFeatureTraversePath
S3 PermissionToTraverseFeature NewWaterTraverseGoalPtPlanned	S3 SetupMovementParams mob_MoveToBypassGoalPt PlanWaterTraverseGoalPts
S3 ClearOfWaterFeature	S0 NormalMovementPossible

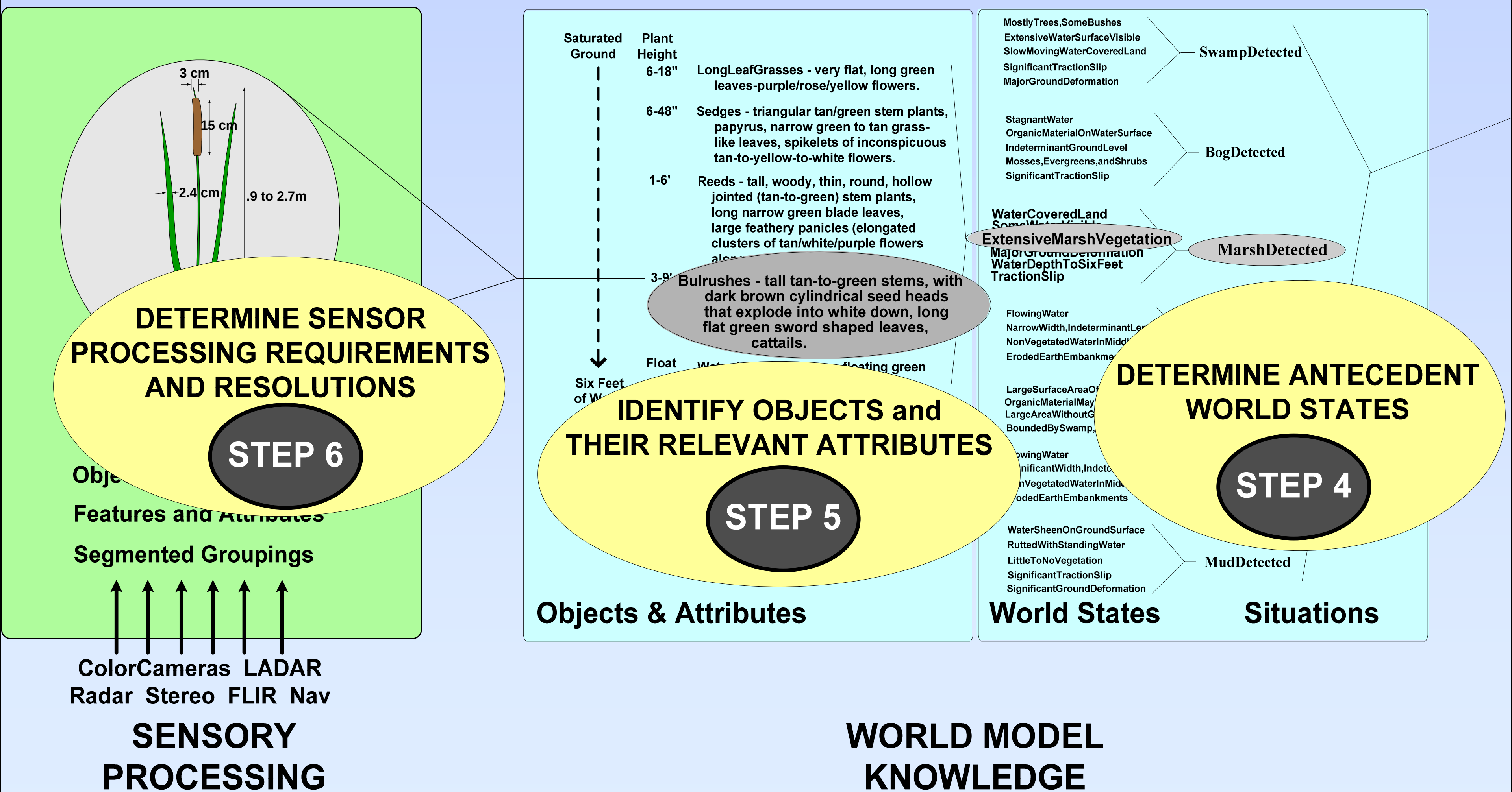
PLAN STATE-TABLE

Condition – Action Rules for Each State

Determine State -Transition Conditions

Identify Objects and Attributes

Determine Sensor Requirements



Software Methodology

This is a tedious process.

There are many tasks in the command library at each level

There are many parameters for each task

There are many objects that must be recognized

There are many situations that must be understood

But, the numbers are not infinite. They are, in fact, quite modest. (One of the advantages of hierarchies.)

RCS Software Development for Autonomous On-Road Driving

Estimated numbers:

- ~ 200 tasks
- ~ 100 parameters
- ~ 1000 transition conditions
- ~ 10,000 objects or events

Other skills may require similar numbers

Current and Near Term

Cognitive reasoning capabilities, planning, and control will enable useful tactical behaviors on the battlefield within a decade

The remaining tall pole in the tent is perception.

Intelligent machines cannot achieve human levels of performance until machine vision systems can perform as well as human vision

Current and Near Term

Sensor technology is well developed – Color, FLIR, Night Vision, and LADAR

What is lacking is the ability to perceive and understand situations and relationships

Machine vision remains far inferior to human capabilities in scene understanding and situation assessment

Long term potential

A solution may lie in
Reverse Engineering the Brain

Cited as a Grand Challenge by
National Academy of Engineering

Subject of a Decade of the Mind Conference
at Sandia National Labs
Jan 13 –15, 2009
http://www.dom4.org/

Recent progress in neuroscience & intelligent systems engineering makes this a promising approach

Reverse Engineering the Brain

Brain imaging is revealing many of the functional operations in the brain

Neural modeling is explaining many of the computational processes in the brain

Computers are approaching the computational power of the brain

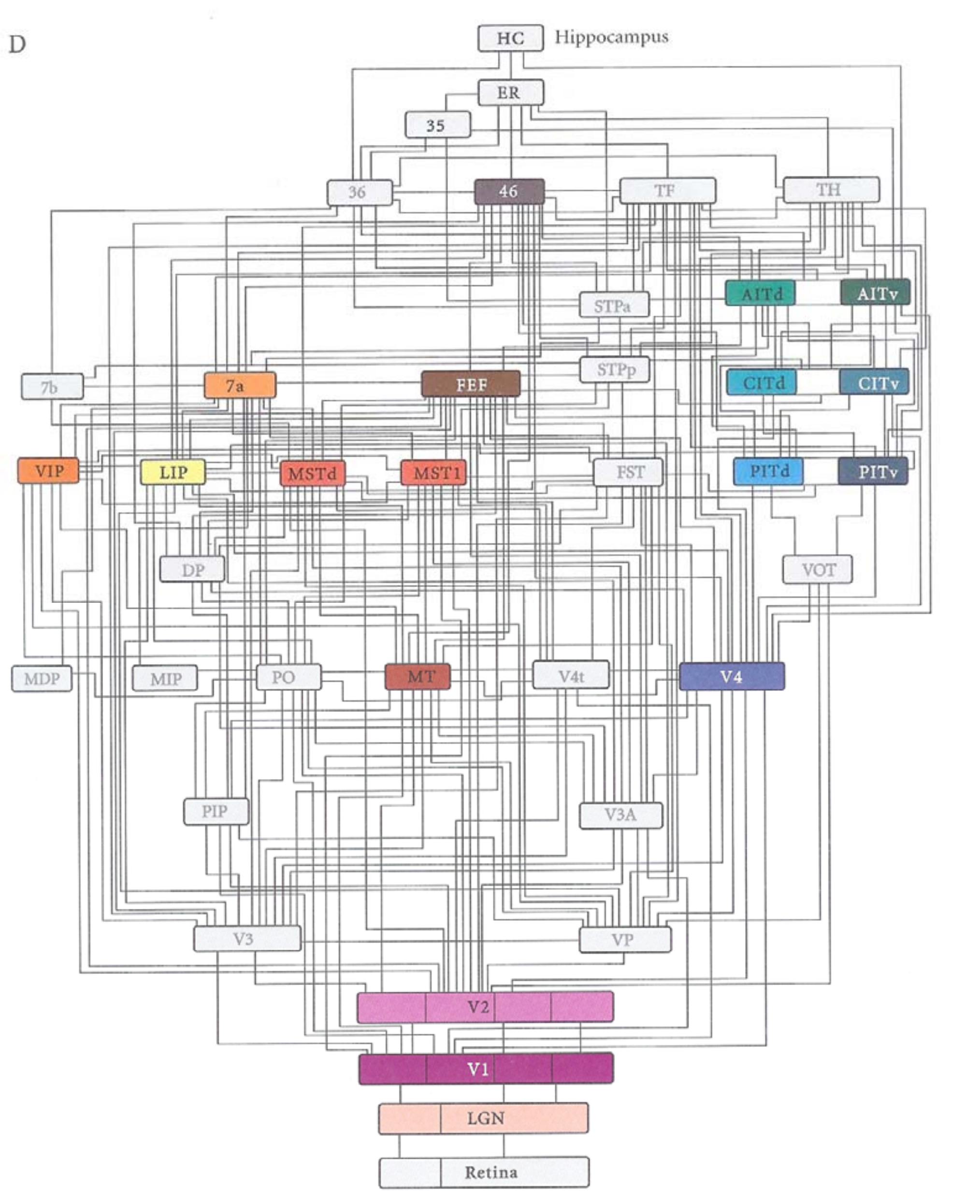
Details of the functionality and connectivity within and between areas in the brain are emerging

Circuit diagram of visual system in brain

12 layers

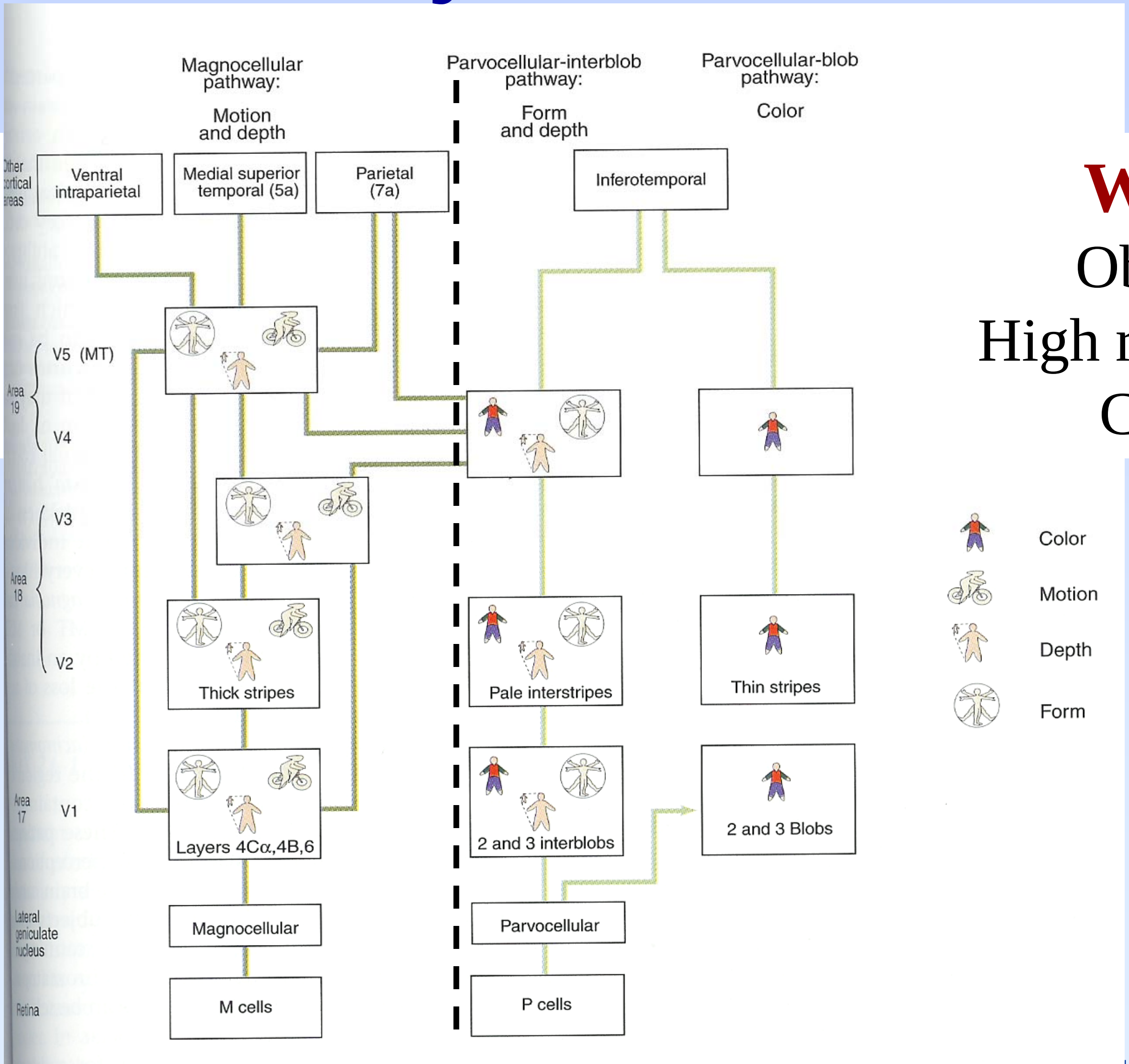
32 areas

Each area is an array of Cortical Computational Units (CCUs)



Functional diagram of CCU arrays in V1-V5

Where
Space
High speed
Motion



What
Objects
High resolution
Color

Long term potential

Detailed circuitry and functionality of CCU arrays in visual cortex are being understood

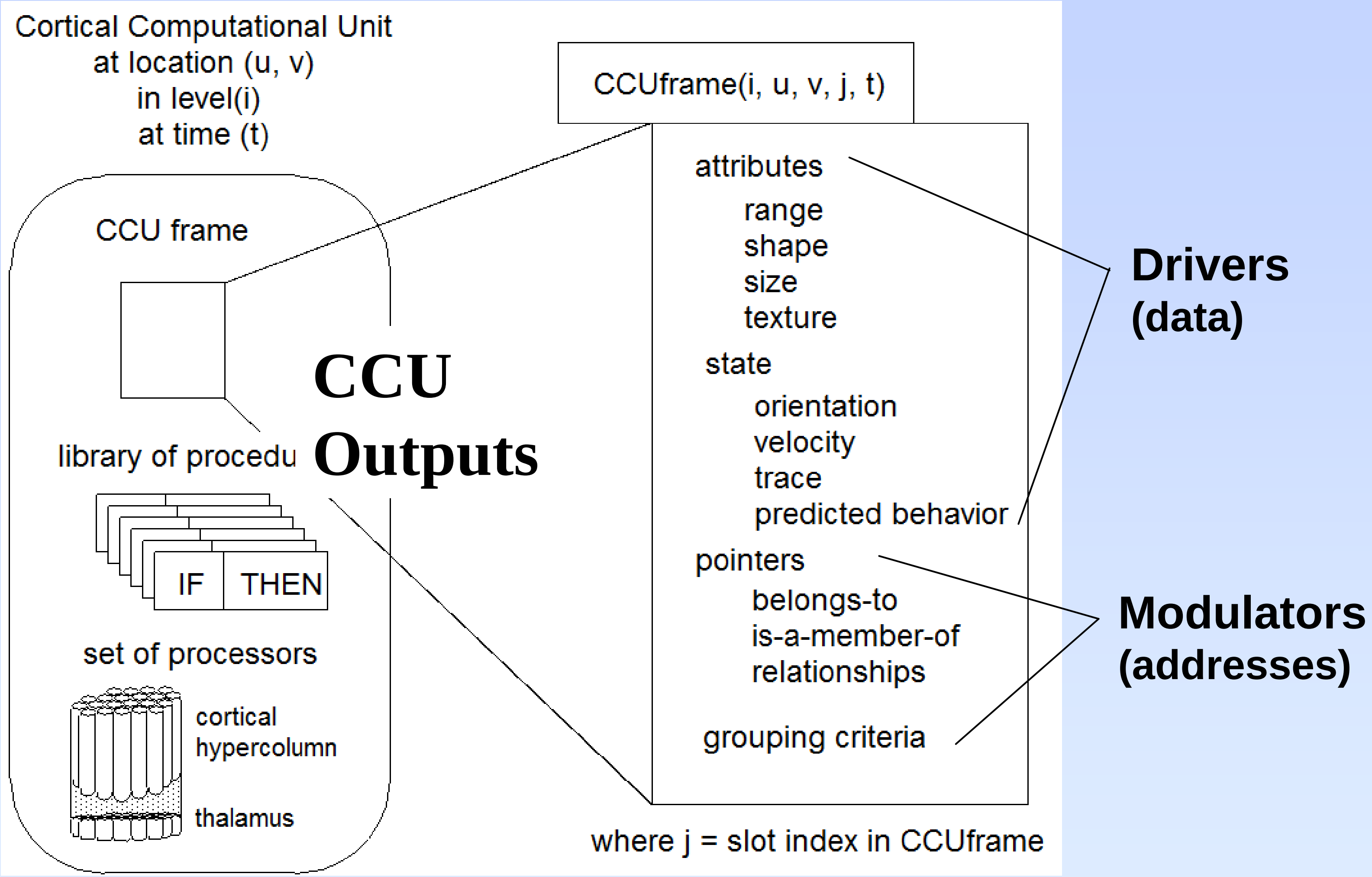
About 1 million CCUs in human brain
About 200,000 CCUs in visual cortex

About 10,000 neurons in each CCU

Connectivity within and between CCUs are being mapped

Inputs and outputs are being discovered

A Theoretical Model of a CCU



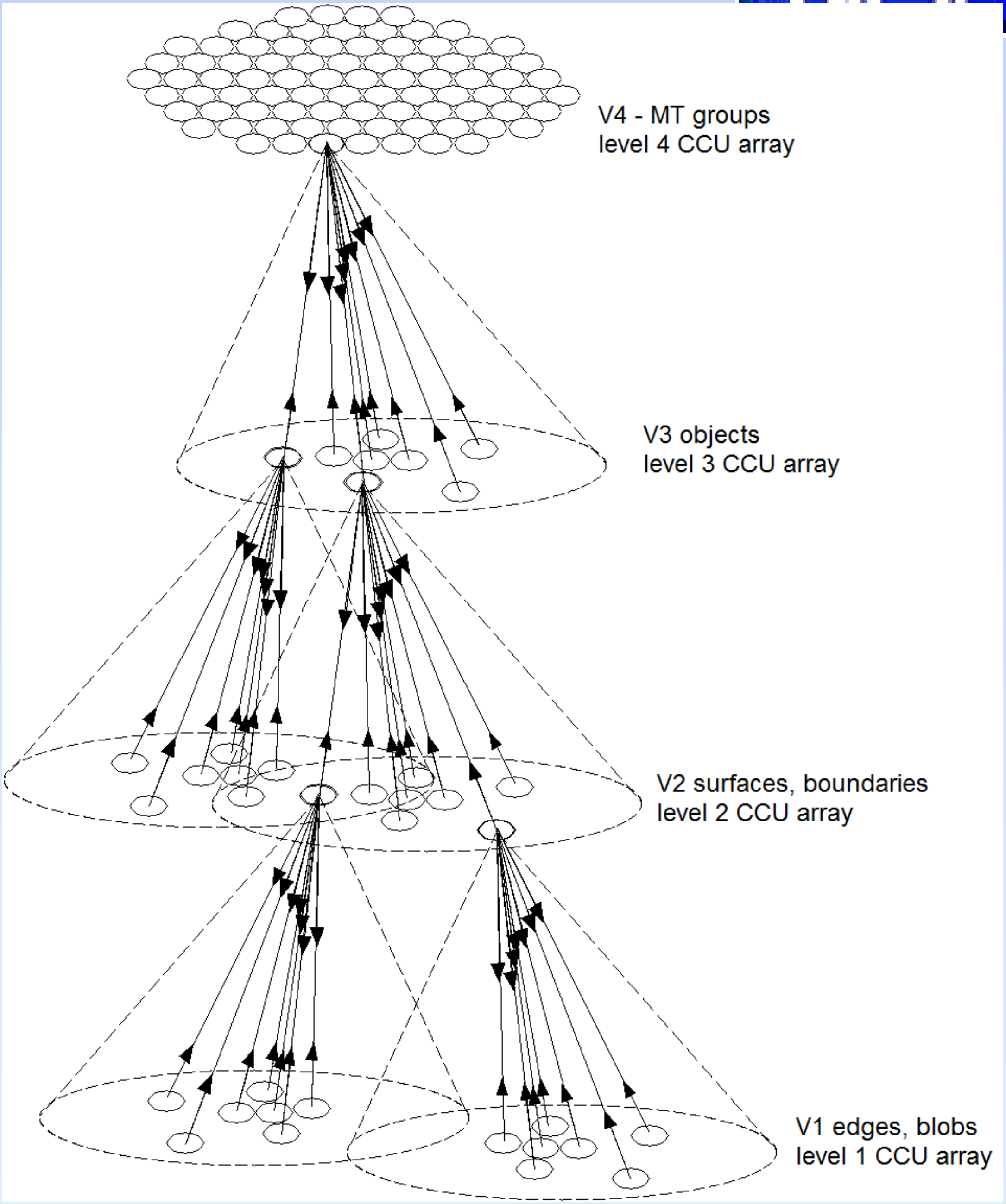
windowing, segmentation, grouping, computing group attributes & state, filtering, classification, setting and breaking relationships

CCU Grouping Hierarchy

Pointers link symbols to pixels & vice versa

Provide symbol grounding

Pointers reset every saccade ~ 150 ms



Long term potential

- **Functional modeling of the human brain at the level of Cortical Computational Units (CCUs) appears within the capacity of current supercomputers**

- **Human level performance in perception, situation awareness, reasoning, planning, and behavior may be feasible on desktop-class machines within two decades**

Summary

Mid term solution to building intelligent robots lies in the 4D/RCS reference model

1. **Bridges the gap between Artificial Intelligence (AI) and modern control theory**

2. **Well documented and tested in a number of applications**

3. **Mature with many software development tools**

Summary

Long term solution to building robots with human level performance may lie in Reverse Engineering the Brain

1. **Neurosciences and brain imaging enable visualization of brain activity during perception, thinking, planning, and acting**

2. **Testable models of computation and representation in the brain are emerging**

3. **Functional modeling of the human brain seems within the capacity of supercomputers today & desktop computers within two decades**

We are at a tipping point

Analogous to where nuclear physics was in 1908

- **Fundamental processes are understood in principle**

Perception	Brain structure and function
World modeling	Cognitive & control architectures
Reasoning	Computational equivalence
Planning	Language
Control	Learning & memory

- **Technology is emerging to conduct definitive experiments**

- **Significant military and economic applications will develop early in the century**

Impact on Military Strength

Intelligent weapons systems will:

- **outperform manned systems**
- **cost less to train**
- **cost less to maintain readiness**
- **keep soldiers out of harm's way**

Intelligent weapons will revolutionize warfare

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